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An Evaluation of the Smith-Feddes Model

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A model designed to produce estimates of water contents and number density distributions at any time and geographical location was published in 1974. Known by its authors names as the "Smith-Feddes", this model is initiated by gridded, data-base information from the 3DNEPH (or RTNEPH) and Hemispherical analyses.

The Smith-Feddes has been used periodically with mixed results and the implicit assumption has been that new, more definitive cloud physics information would improve the model's consistency. The Air Force Geophysics Laboratory decided to investigate the possibility of improving this model to develop it into a useful tool for future Air Force planning and operations.

The initial phase of this study was essentially an exercise to gain familiarity with both the Smith-Feddes and the initiating analyses. Three weather situations were defined by water content and temperature-versus-altitude profiles derived from aircraft measurements. The model was then exercised for the same situations and the results of the separate analyses were then compared.

This report describes this investigation and details our observations and conclusions based on the results of this comparison study.

It is ~~our~~ recommend~~ation~~ that no further time be expended in an effort to improve the 3DNEPH RTNEPH, Smith-Feddes model, as we concluded that it is unable to consistently produce water-content values within reasonable error bounds. However, it ~~is our opinion that~~ certain cloud-physics concepts used in the model may be incorporated in a new model specifically designed to produce cloud and precipitation estimates from climatological data.

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PREFACE

The authors express their appreciation for the assistance and advice they received during the execution of this project and in the preparation of this report:

To Dr. Arnold A. Barnes, Jr., who initiated the project, for the preliminary spadework and for obtaining the operational version of the Calspan update of the Smith-Feddes model from the US Navy. To Lt. Pam Beecher of the AFGL Staff Meteorology Office for securing the 3DNEPH, NHA and terrain data from USAFETAC. To Morton Glass and Vernon G. Plank for advice based on their expertise in Cloud Physics.

Special thanks are given to SSgt Charles C. Crouch for the time and effort he expended on the AFGL computer on both the updated program and in the reduction of the aircraft data.

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ILLUSTRATIONS

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AN EVALUATION OF THE SMITH-FEDDES MODEL

1. INTRODUCTION

A report entitled "A Synoptic-Scale Model for Simulating Condensed Atmospheric Moisture" was published by the USAF Environmental Technical Applications Center (USAFETAC) in June, 1974.[1,2] The model is commonly referred to as the "Smith-Feddes" and is described as one "designed to use operationally-produced, gridded global analyses to produce a 'best estimate' of condensed moisture content, its thermodynamic phase and the resultant drop-size distributions at a point in space and time." The input data are from the Air Force Global Weather Central's two distinct, gridded data bases,[3] the Global Cloud Analysis (3DNEPH)* and the Hemispherical Analysis.

The Smith-Feddes, hereafter referred to as S/F, has been exercised periodically throughout the years with mixed results.[4,5] One such instance was the Air Force Geophysics Laboratory's (AFGL) test of the

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*The 3DNEPH was replaced by a new analysis (RTNEPH) in 1984 with the primary difference being in the database definition of the vertical structure. The Smith-Feddes model has been modified to accept cloud information in the RTNEPH format.[7]

1 Smith, Robert D. (1974) *Atmospheric Moisture Parameterization*, USAFETAC 74-1

2 Feddes, Robert G. (1974) *A Synoptic-Scale Model for Simulating Condensed Atmospheric Moisture*, USAFETAC 74-4

3 Feddes, Robert G. (1974) *Development of a Gridded Data Base*, USAFETAC 74-2

4 Peirce, R.M., Lenhard, R.W. and Weiss, B.F. (1975) *Comparison Study of Models Used to Prescribe Hydrometeor Water Content Values, Part I: Preliminary Results*, AFCRL-TR-75-0470 ADA019633

5 Touart, Chankey and Izumi, Yutaka (1979) *Comparison Study of Models Used to Prescribe Hydrometeor Water Content Values, Part II: USSR Data*, AFGL-TR-79-0213 ADA082385

S/F during the Missile Erosion Program at Wallops Island, VA. The results did not produce liquid-water-content (LWC) determinations with the desired degree of accuracy. AFGL, at that time, decided to forego the S/F and continued to develop a technique to use radar-aircraft sensing to provide LWC profiles along missile trajectories.[6]

A model giving reasonably accurate definitions of atmospheric water contents has many varied applications in Air Force and other government planning and operations. Because of this, there have been many queries about refining the S/F to incorporate new scientific information. The S/F was, in fact, updated for the US Navy by the Arvin/Calspan Advanced Technology Center in 1984-85.[7]

AFGL decided to investigate the S/F with the objective of "fine tuning" and developing the model into a reliable tool for use in future Air Force operations. We approached the study with the assumption that the model was a viable technique based on sound meteorological principles. Our plans were to exercise the model in conjunction with field studies of differing weather situations where all essential parameters were well documented. Thus, any problem areas where the S/F did not conform to "ground truth" measurements could be identified and adjusted.

The S/F was originally composed of a series of look-up tables and equations that related 3DNEPH information on clouds (types, heights, depths, etc.) and existing surface weather conditions with temperatures from the Hemispherical Analysis to produce estimated LWC-altitude profiles. The model has since been modified to accept RTNEPH information and to compute condensed moisture content from moist adiabatic ascent for all noncirriform clouds. The adiabatic water content of cumuliform clouds was reduced to account for entrainment.[7]

Thus, the S/F is heavily dependent upon the accuracy of the initiating input data. With this in mind, it may be better to consider the S/F as an extended form of the 3DNEPH/RTNEPH. Therefore, any thorough evaluation of the S/F must also include similar evaluations of the 3DNEPH/RTNEPH and Hemispherical Analysis input data.

Before expending time and effort in researching and obtaining studies where all essential parameters were well documented, we decided that a quick comparison of a few values from the S/F inputs and output with past recorded aircraft (A/C) measurements might produce some useful information.

Although A/C measurements[8] alone do not contain enough definitive information for a thorough comparison, it was reasoned that the exercise would provide some familiarization with the S/F and input analyses. The results of such tests could also indicate possible problem areas and might give insight as to the necessary efforts needed to fulfill our planned objective.

This report describes the initial effort and our conclusions based on the results.

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6 Plank, Vernon G. (1977) *Hydrometeor Data and Analytical-Theoretical Investigations Pertaining to the SAMS Rain Erosion Program of the 1972-73 Season at Wallops Island, Virginia*, AFGL/SAMS Report No. 5, AFGL-TR-77-0149 ADA051192

7 Rogers, William C., Hanley, James T. and Mack, Eugene J. (1985) *Updating the Smith-Feddes Model*, Calspan Report No. 7330-1, Final report to Naval Environmental Prediction Research Facility, Monterey, CA Contract No. N00228-84-C-3157

8 Barnes, Arnold A., Cohen, Ian D. and McLeod, Donald W. (1982) *Investigations of Large Scale Storm Systems Final Report*, AFGL-TR-82-0169 ADA119862

2. AIRCRAFT TEST DATA

A search of the old AFGL A/C files produced many possible candidates for use in a comparison study. Although the vast majority of the recorded data were from constant altitude flights at distinct levels in particular storm situations, we found several cases where the A/C made spiral descents through storm depths. These flights were graded in respect to data quality, time durations, altitude coverages, cloud and precipitation LWC and geographical locations. The data chosen for the comparison studies were from Flight E80-10 taken on 25 February 1980 over the Washington State coastline; Flight E80-11 taken on 26 February 1980 over the ocean off the Washington coast and Flight E80-36 taken on 15 December 1980 above the Canton, Ohio area. These data provide time-resolved values of temperatures, altitudes and cloud and precipitation number densities from PMS, 1-D probes[9] that were converted into LWC.

Figure 1 is a temperature vs altitude plot for each flight with the start and stop times noted. Figure 2 shows the total LWC in respect to altitude as determined from the A/C measurements for each flight. Figures 3, 4 and 5 show the contributions of cloud and precipitation LWC to the total for each flight.

These plots indicate that the February storm situations contain approximately the same amount of cloud LWC and that the larger LWC totals are mainly the result of precipitation. On 15 December, the data show very little precipitation with the majority of total water content being contained in cloud-sized hydrometeors.

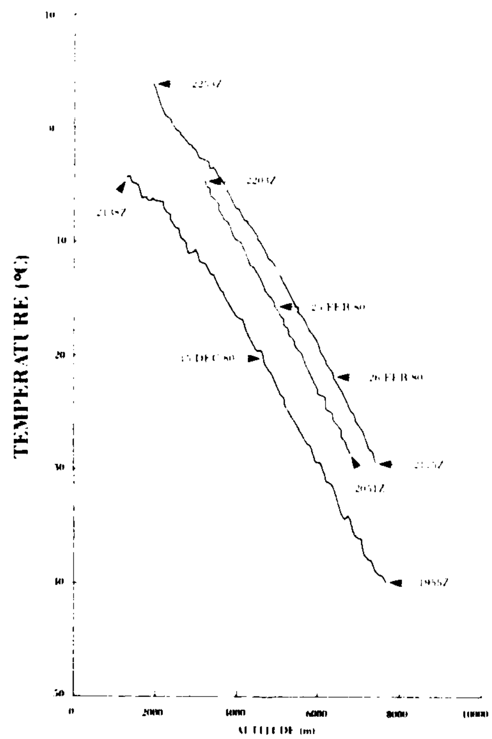

Figure 1. Temperature vs Altitude from the Three Comparison Aircraft Flights.

9 Knollenberg, R.G. (1970) The optical array: an alternative to scattering or extinction for airborne particle size determinations, *J. Appl. Meteorol.*, *9* (No. 1):86-103.

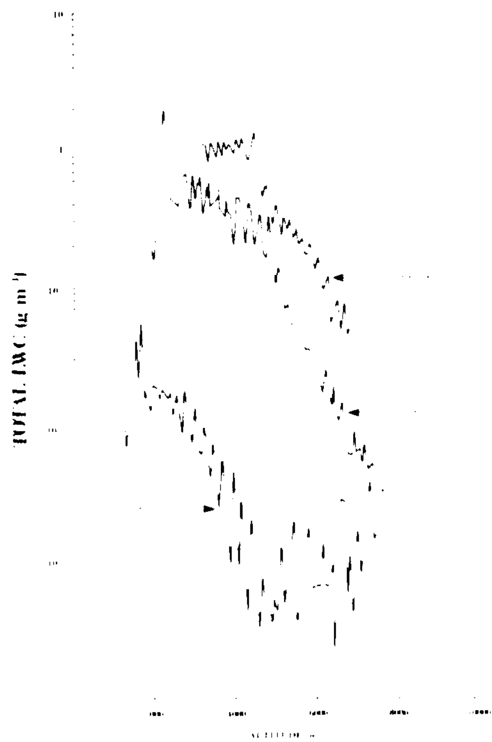

Figure 2. Total Liquid Water Content vs Altitude from Measurements Taken During the Three Comparison Aircraft Flights.

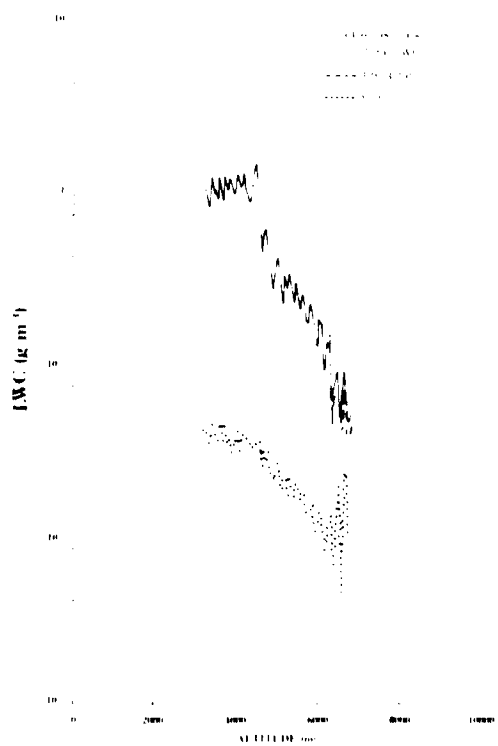

Figure 3. Total, Cloud and Precipitation Liquid Water Content vs Altitude for Flight E80-10 on 25 February 1980.

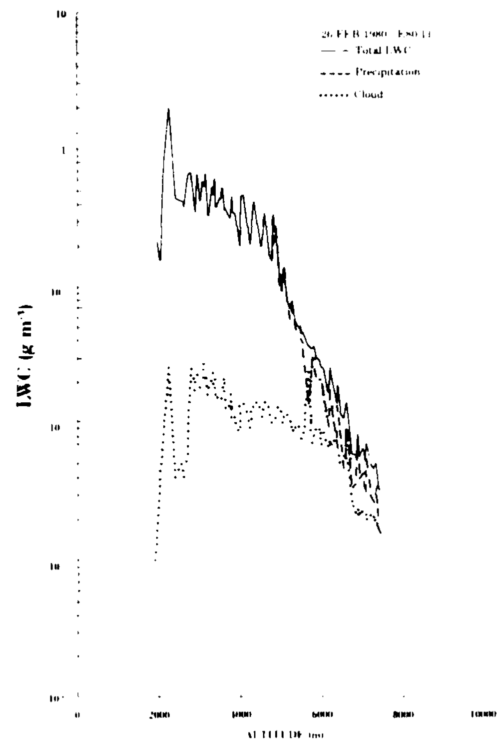

Figure 4. Total, Cloud and Precipitation Liquid Water Content vs Altitude for Flight E80-11 on 26 February 1980.

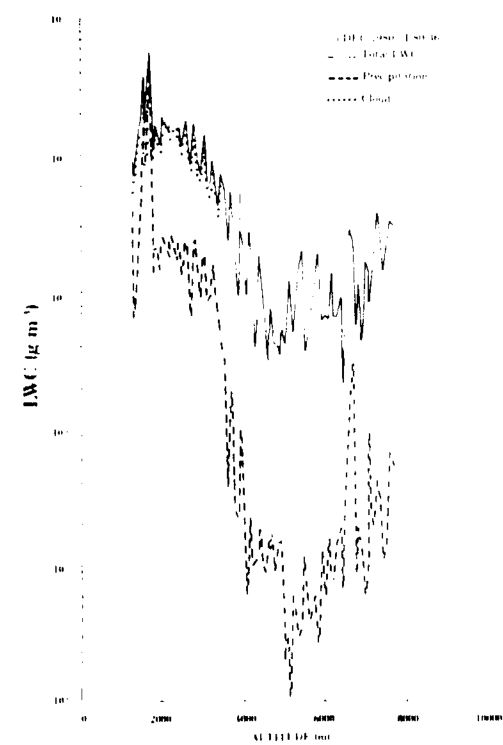

Figure 5. Total, Cloud and Precipitation Liquid Water Content vs Altitude for Flight E80-36 on 15 December 1980.

3. GLOBAL ANALYSES

The S/F initializing information was acquired from USAFETAC through the much appreciated efforts and cooperation of the AFGL Staff Meteorology Office.

From the latitudinal and longitudinal coordinates and times of each of the spiral flights, we received (1) terrain heights, (2) temperature-altitude values from the Northern Hemispherical Analysis (NHA) and (3) a coded printout of the 3DNEPH analysis. (Since the flight dates were in 1980, RTNEPH data were not available.)

The terrain heights were 30 m for the shore-line 25 February flight, 0 m for the over-the-ocean 26 February flight and 300 m for the Ohio flight on 15 December.

The NHA data is produced twice daily at 0000Z and 1200Z. Figures 6, 7 and 8 are plots of the NHA temperatures vs altitudes for 1200Z on each particular day and for 0000Z the following day. The corresponding A/C temperature profiles are superimposed on these plots for comparison.

The 3DNEPH is produced every 3 hours starting at 0000Z. The 2100Z analysis for each flight date was used since it was nearest to the A/C time. Table 1 lists the decoded 3DNEPH records as per the decoding instructions in USAFETAC 74-3.

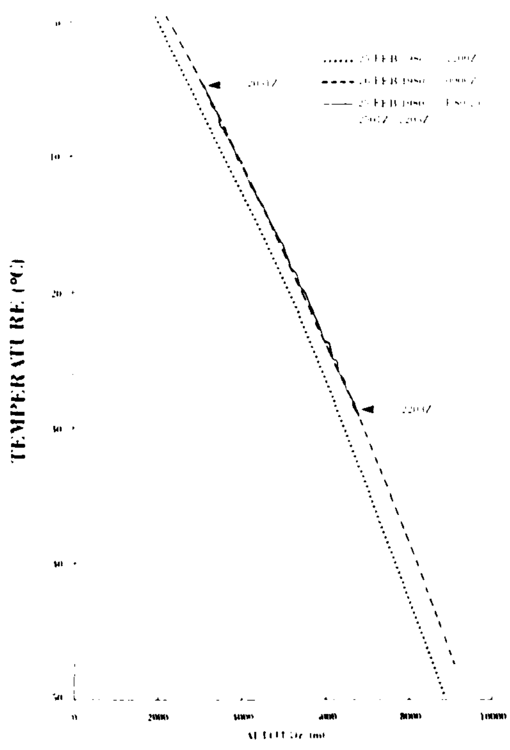

Figure 6. Temperature vs Altitude from Flight E80-10 on 25 February 1980 with Those from the Northern Hemispherical Analyses Before and After Flight Times.

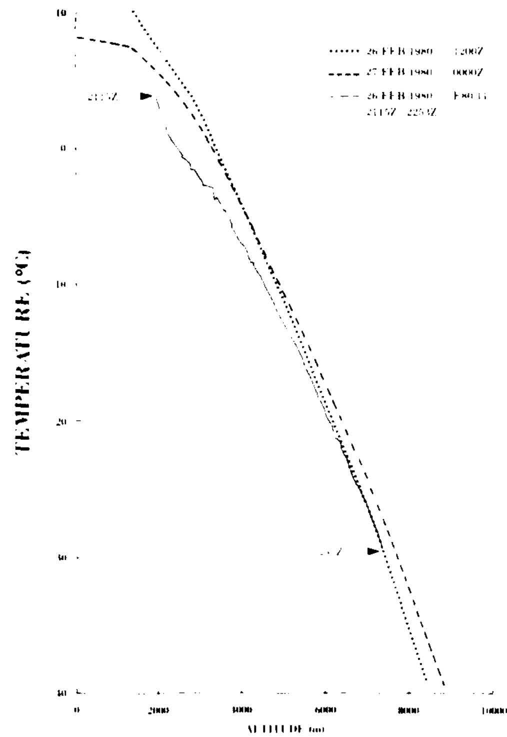

Figure 7. Temperature vs Altitude from Flight E80-11 on 26 February 1980 with Those from the Northern Hemispherical Analyses Before and After Flight Times.

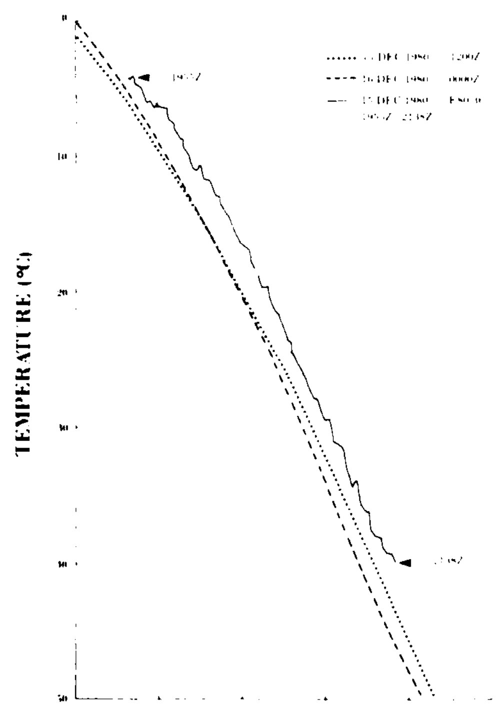

Figure 8. Temperature vs Altitude from Flight E80-36 on 15 December 1980 with Those from the Northern Hemispherical Analyses Before and After Flight Times.

Table 1. **Decoded Information from the Recorded 2100Z 3DNEPH Analysis for the Aircraft Flight Dates**

(2100Z)		25 Feb 80	26 Feb 80	15 Dec 80
Present Weather		NIL	RAIN	SNOW
Cloud Type	Low	SC	SC & CU	SC
	Mid	NS	NS	NS
	High	*	CS	CS
Cloud Heights			(Feet)	
	Max Top	22000	40000	40000
	Min Base	3500	1000	4500
Cloud Cover	(Feet)		(Percent)	
Layer	Base - Top	0	0	0
AGL 1	SFC - 150	0	0	0
AGL 2	151 - 300	0	0	0
AGL 3	301 - 600	0	0	0
AGL 4	601 - 1000	0	100	0
AGL 5	1001 - 2000	0	100	0
AGL 6	2001 - 3500	0	100	0
MSL 7	3501 - 5000	100	100	100
MSL 8	5001 - 6500	100	100	100
MSL 9	6501 - 10000	100	100	100
MSL 10	10001 - 14000	100	100	100
MSL 11	14001 - 18000	100	100	100
MSL 12	18001 - 22000	50	100	100
MSL 13	22001 - 26000	0	100	0
MSL 14	26001 - 35000	0	100	100
MSL 15	35001 - 55000	0	100	100
	Total	96	100	100

* - Unknown or Not Present

4. SMITH-FEDDES ANALYSIS

The updated program version of the S/F[7] was used in this comparison study. The complete computer program is designed to accept the NHA, RTNEPH, and terrain outputs, and then decode, interpret, and apply the refined data to the cloud physics relationships in the S/F model. We bypassed the initial part of the program by applying the decoded data from Table 1 directly to the actual S/F portion in the acceptable format.

The 3DNEPH present weather for the 25 February storm was listed as "nil" but we judged it should have been classified as rain in view of the temperature profile, the A/C data, and its similarity to the 26 February case. Without surface precipitation, we could not calculate any precipitation throughout the storm's depth.

The precipitation calculations in the modified S/F version required a further breakdown of present weather that is available from the RTNEPH but was not included in our 3DNEPH data, that being the degree or intensity of surface precipitation. We decided that "moderate rain" classifications were conservative estimates for both 25 and 26 February.

The present weather for the 15 December was listed as "solid precipitation not in showers at the time of observation" that we shortened to snow. The A/C data indicated that little would be reaching the ground, thus, we judged that a "light intermittent snow" classification would be appropriate.

Tables 2, 3, and 4 show the total LWC for each of the test dates along with the contributions of cloud and precipitation LWC as estimated by the S/F model. All three tables show no precipitation in cloud layer 8 (~ 1700m). This problem is possibly associated with the application of the cloud data in the 3DNEPH format to the updated S/F version.

Table 2. Liquid Water Contents at 13 Altitudes on 25 February 1980 as Derived from the Smith-Feddes Model.

Layer	Mid Height (Meters)	LWC ($g\ m^{-3}$) Total	Cloud	Precip.
1	53	.084	0	.084
2	99	.084	0	.084
3	167	.084	0	.084
4	274	.084	0	.084
5	488	.084	0	.084
6	820	.084	0	.084
7	1262	.286	.201	.084
8	1712	.320	.320	0
9	2474	2.237	.885	1.351
10	3659	2.345	2.345	0
11	4834	3.345	3.345	0
12	6000	.313	.313	0
13	7264	0	0	0

Table 3. Liquid Water Content at 13 Altitudes on 26 February 1980 as Derived from the Smith-Feddes Model.

Layer	Mid Height (Meters)	LWC ($g\ m^{-3}$) Total	Cloud	Precip.
1	23	.239	0	.239
2	69	.239	0	.239
3	137	.239	0	.239
4	244	.239	0	.239
5	352	.239	0	.239
6	733	.498	.259	.239
7	1259	.618	.399	.219
8	1712	.401	.401	0
9	2474	2.489	.985	1.504
10	3659	3.769	2.655	1.113
11	4878	3.896	3.896	0
12	6044	4.665	4.665	0
13	7263	.140	.060	.080

Table 4. Liquid Water Content at 13 Altitudes on 15 December 1980 as Derived from the Smith-Feddes Model.

Layer	Mid Height (Meters)	LWC ($g\ m^{-3}$) Total	Cloud	Precip.
1	323	.115		.115
2	369	.115	0	.115
3	437	.115	0	.115
4	544	.115	0	.115
5	758	.115	0	.115
6	1105	.115	0	.115
7	1412	.190	.075	.115
8	1712	.176	.176	0
9	2474	1.454	.576	.878
10	3659	1.993	1.404	.589
11	4878	1.863	1.863	0
12	6044	2.061	2.061	0
13	7200	0	0	0

5. DATA COMPARISON

5.1 Temperature

Since all three A/C flights were conducted within the 2000Z to 2300Z time range, we compared the A/C values with the NHA temperatures from the 0000Z analyses. Figure 9 shows the temperature differences between those from the NHA minus those from each A/C flight.

The temperatures on 25 February were quite comparable. On 26 February, the NHA values ranged from 2 to 4° C higher and on 15 December 2 to 5° C lower.

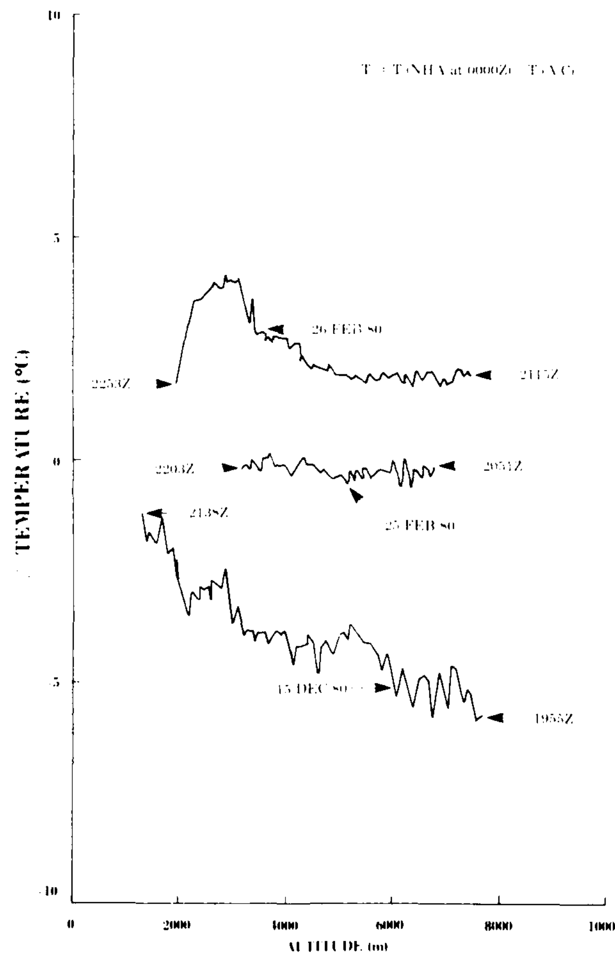

Figure 9. Temperature Differences Between Those from the Northern Hemispherical Analysis at 0000Z and Each Aircraft Flight.

5.2 Liquid Water Content

Data obtained from the S/F analyses were plotted with those acquired from the A/C measurements for easy visual comparison. Figures 10, 11, and 12 show the total LWC; Figures 13, 14, and 15, the cloud LWC; and Figures 16, 17, and 18, the values for precipitation.

In all three cases, the S/F cloud water (Figures 13, 14, and 15) content was substantially higher (factor of ~1000) than the A/C measurements indicated. Questions, of course, may be raised as the absolute accuracy of the A/C data, yet it is difficult to envision PMS, 1-D errors that would relate to these differences in magnitude. Also, the cloud type may be changed to lower the S/F values but such a "what if" exercise is unwarranted as cloud types were specified in the 3DNEPH information.

Precipitation LWC for the February storms (Figures 16 and 17) show the few S/F calculations to be "in the same ballpark" as those from the A/C measurements. For 15 December, (Figure 18) the S/F precipitation values are considerably higher than the A/C determinations. In all three cases, the LWC values at cloud layer 8 should probably approximate the values of the dashed lines that bridge this region in the precipitation plots. The disturbing feature in these plots is the lack of S/F precipitation at altitudes where the A/C data clearly show it to be present.

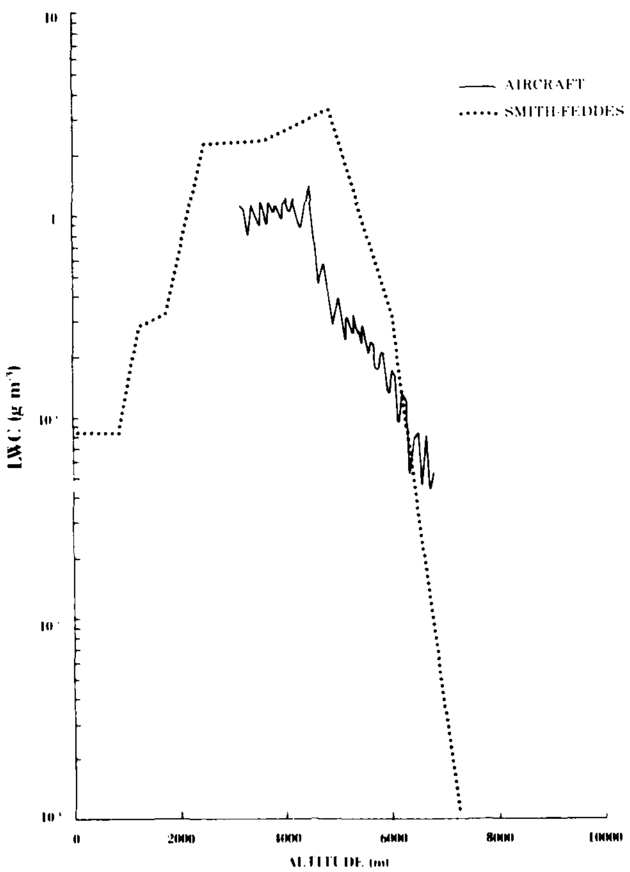

Figure 10. Total LWC Derived from the Smith-Feddes Model and Those from Aircraft Measurements for 25 February 1980.

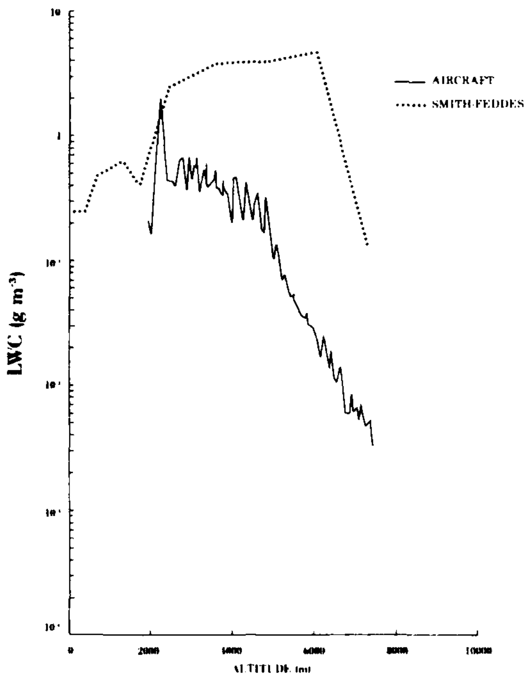

Figure 11. Total LWC Derived from the Smith-Feddes Model and Those from Aircraft Measurements for 26 February 1980.

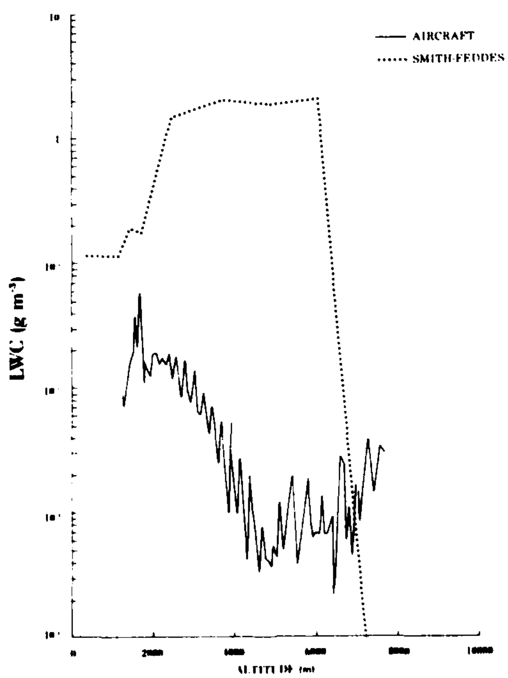

Figure 12. Total LWC Derived from the Smith-Feddes Model and Those from Aircraft Measurements for 15 December 1980.

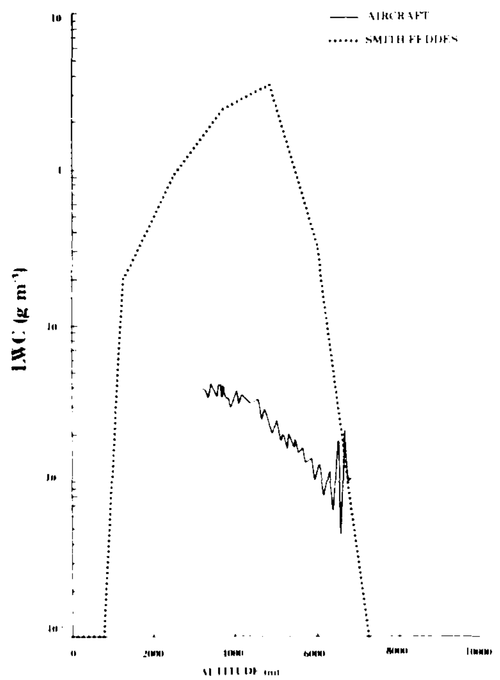

Figure 13. Cloud LWC Derived from the Smith-Feddes Model and Those from Aircraft Measurements for 25 February 1980.

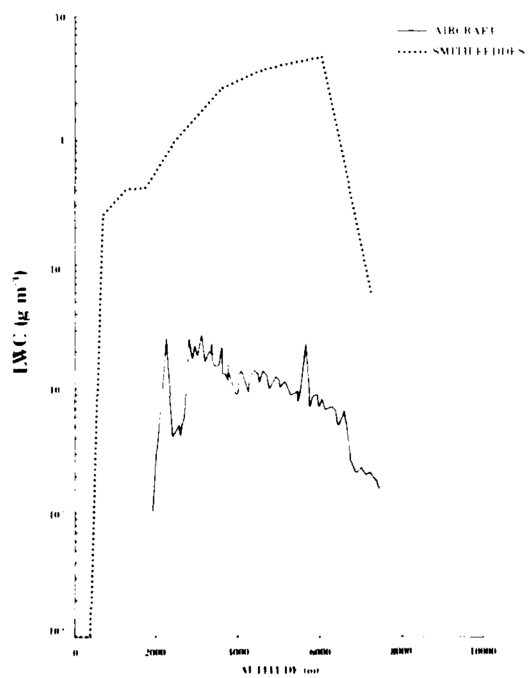

Figure 14. Cloud LWC Derived from the Smith-Feddes Model and Those from Aircraft Measurements for 26 February 1980.

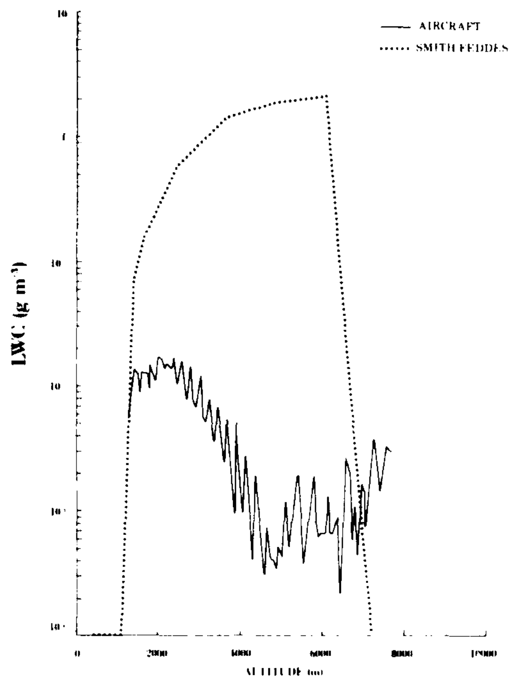

Figure 15. Cloud LWC Derived from the Smith-Feddes Model and Those from Aircraft Measurements for 15 December 1980.

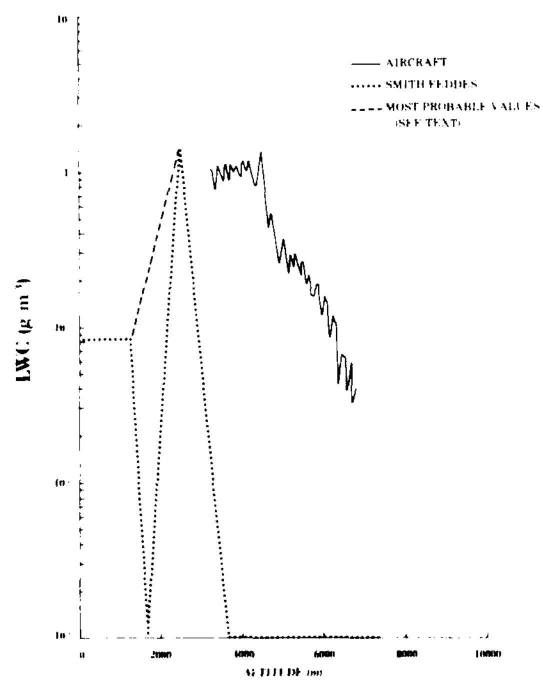

Figure 16. Precipitation LWC Derived from the Smith-Feddes Model and Those from Aircraft Measurements for 25 February 1980.

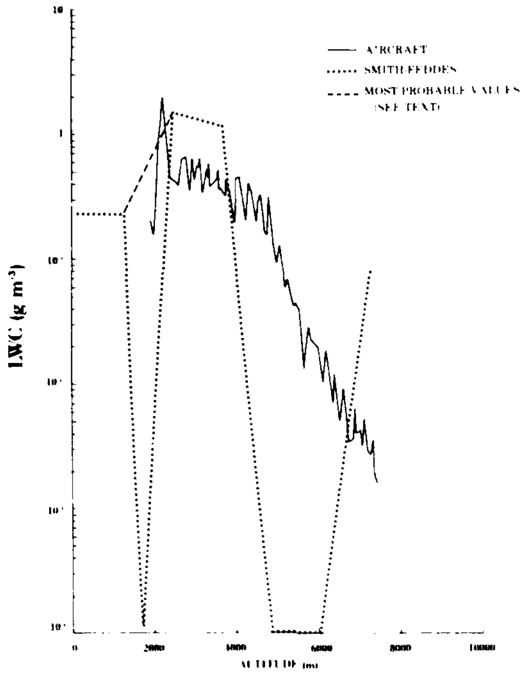

Figure 17. Precipitation LWC Derived from the Smith-Feddes Model and Those from Aircraft Measurements for 26 February 1980.

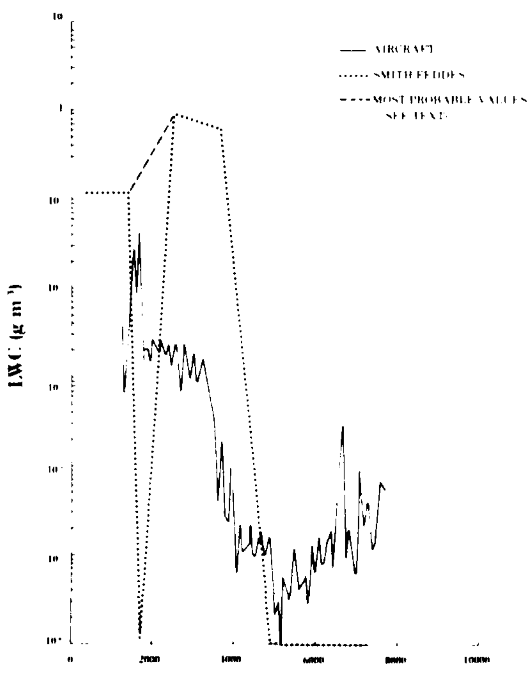

Figure 18. Precipitation LWC Derived from the Smith-Feddes Model and Those from Aircraft Measurements for 15 December 1980.

6. OBSERVATIONS AND CONCLUSIONS

As previously mentioned in Section 1, we never intended, at this time, to delve into the particular problems of A/C measurements or those associated with the 3DNEPH or RTNEPH—S/F analyses.

We have used derived LWC from A/C data as "standards" fully realizing that uncertainties exist in both the measurement processes and in the LWC determinations especially where ice hydrometeors are converted into equivalent masses of liquid water. However, since the A/C did traverse the major portion of the storms' depths, albeit in a spiral pattern, we feel that the LWC "standards" are somewhat representative of the cloud and precipitation water that were present at those times.

We terminated this study with the derivation of LWC, although the S/F is capable of producing number density distributions that could have been compared with those measured with the 1-D instruments. That comparison would have been a wasted effort since LWC is the direct result of the numbers and sizes of the hydrometeors; thus, differences in one means similar discrepancies in the other.

This familiarization exercise enabled us to make some observations and form some conclusions in respect to the 3DNEPH/RTNEPH—S/F model.

First, the S/F is not a predictive or even a real-time model as it relies upon a complicated combination of satellite and weather measurements and observations that culminate in a 3DNEPH or RTNEPH analysis. Contrary to what some might think, the best that may be obtained are estimates of past weather situations. This fact alone limits the model's use to very particular situations.

Second, the best, most-up-to-date cloud physics relationships used to describe water contents from cloud types, depths, and temperatures have been derived from highly variable data and are not known with enough precision to form estimates of reasonable accuracy.

Third, temperature changes affect both cloud and precipitation LWC. Since temperature determinations are limited to the NHA, twice-daily height profiles, there may be considerable uncertainty between reporting times, especially in rapidly changing weather situations.

Fourth, the 3DNEPH or RTNEPH analysis was not designed to, and cannot supply, the necessary precise, definitive information to initiate an S/F type model even in areas where weather reporting stations are available. In remote areas of the world, where some envision the use of this model, the results could be misleading.

Finally, we have concluded that the 3DNEPH/RTNEPH—S/F model is unable to consistently produce LWC values within reasonable error bounds. At best, determinations from the S/F can only be considered "best guesses" tempered with a high degree of probability. It is our opinion that any model designed to estimate reliable LWC profiles and number densities required for calculating erosion, attenuation, etc., must be based on some type of quantitative, real-time measurements (such as, but not restricted to, weather radar, LIDAR, etc.) because of the inherent variabilities of complex weather processes.

7. RECOMMENDATIONS

Our observations and conclusions lead us to recommend that AFGL not expend any further effort to improve the 3DNEPH/RTNEPH—S/F model. We believe that a real-time, global, LWC model will have to await the operation of a reliable, satellite-sensing system to supply some altitude-defined, quantitative measurements with considerably smaller "footprint" on which reasonable estimates may be based.

It is also our opinion that the more viable, cloud-physics concepts used in the S/F may be salvaged and incorporated into a new model specifically designed to produce "best guess" cloud and precipitation estimates based entirely on climatological data. Such information may be beneficial for operational planning.

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